musical tones were aimed directly at the determination of this duration. In these experiments the ability to *recognize* a given tone was used as the test of the integrity of the memory-image instead of the ability to *reproduce* it which was used in the experiments of this paper. It is not surprising, therefore, that the duration found by Wolfe should be larger, extending to as much as sixty seconds. The fact that Wolfe's experiments were made with concentrated attention, and those of this paper with distracted attention, is also important, though single tones would not form many associative bonds, except perhaps with very musical subjects. The percentages of right answers are not directly comparable in the two studies, because of the greater opportunity for error with the groups of digits, but there is nothing overtly contradictory in them. The tendency of the digits to re-enter consciousness, observed by *S* and *D*, is undoubtedly the same that gives the periodic improvement of memory in Wolfe's curves.

X. On the Least Observable Interval Between Stimuli Addressed to Disparate Senses and to Different Organs of the Same Sense.

By Alice J. Hamlin.[1]

The figures commonly given by the text-books for this interval are taken from work done by Exner nearly twenty years ago and, so far as the writer is aware, since repeated only in part.[2] The object of the following experiments

[1] Student at the Summer School, 1894.

[2] Exner, *Pflüger's Archiv.*, XI, 1875, 403-432. The statements in the text-books leave it open to the reader to infer that the figures are for single pairs of stimuli, (a single visual stimulus, for example, followed by a single auditory stimulus)—such at least was the conception under which these experiments were undertaken. When, however, Exner's original paper was examined, it was found that his method, except in the case of separate stimuli to the two ears, was such as to give him a series of pairs of stimuli instead of a single pair (pp. 405, 419-20, 423, 426). This may be represented diagrammatically as follows, letting (*a*) stand for auditory and (*v*) for visual:

(Auditory first).	*av.*———	*av.*———	*av.*———	*av.*———	*av.*———	*av.*
(Visual first).	*va.*———	*va.*———	*va.*———	*va.*———	*va.*———	*va.*

In the writer's experiments, on the contrary, single pairs (or triplets) of stimuli were used without exception, *e. g.*, either *av* or *va*. The importance of this difference will appear in the discussion of results below. The work of von Tschisch (*Phil. Stud.*, II, 603), of Angell and Pierce (this Journal, IV, 528), and of Jastrow and

was a remeasurement of this interval for single pairs of stimuli under varying conditions of attention. An attempt has been made at the same time to notice accurately the subjective conditions, in the hope of finding by means of this introspection what the psychological basis may be for such discriminations. In most of the experiments only two stimuli were used, giving the following combinations: Eye and ear, eye and hand (electrical stimulation), ear and hand, right ear and left ear, right hand and left hand. The combination of right eye and left eye, upon which Dvorák has made experiments, was undertaken by a fellow student and was consequently omitted. In a few experiments, stimuli to eye, ear and hand were used at once in a way which will be more fully explained below.

Apparatus and Method. The eye stimulus was always the flash of a small Geissler tube, the ear stimulus was generally the click of a telephone in the secondary circuit of a sliding induction coil (sometimes, however, the snap of an induction spark), and the hand stimulus a moderate induction shock in the tips of the middle and fore fingers. An almost unavoidable difficulty in using stimuli produced by induction apparatus is the variation in intensity. Reason will be given below for believing that moderate variations are without marked effect in such experiments as these. Nevertheless the variations were made as small as possible, and when the subject believed that he was influenced by them, the trial in question was discarded. The apparatus by which these stimuli were managed is fully described in the next of these "Minor Studies," It consisted essentially of a pendulum contact-breaker by which three electrical circuits could be broken at known and exactly adjustable intervals of time. These circuits in the further description will be called *a*, *b* and *c*. The range of possible intervals was from 0 to 44σ; those used varied from 18σ to 44σ. The exactness with which the intervals were kept by the instrument as shown by

Moorehouse, (this JOURNAL, V, 239), is unlike that of the writer for the same reason as Exner's. In the *Revue Scientifique* (XXXIX, 585) Bloch gives the results of experiments on this matter, but is so meager in the description of his methods that it is impossible to decide whether his results are comparable with those of the writer or not. Gonnessiat (*Recherches sur l'équation personnelle*, Paris, 1892, pp. 138-140) has measured the interval by which a visual stimulus may precede an auditory, and yet both seem simultaneous. And finally, Dr. F. Tracy has in this laboratory measured the just observable interval between a sight and a sound by a method practically identical with that about to be described. His results have been kindly placed at the disposal of the writer, and for them her acknowledgments are due. The results have been inserted below in their proper connections.

chronographic tracings was amply sufficient, the mean variation in no case being as great as one part in 100. In the experiments with two stimuli, it was customary to place the apparatus for one (*e. g.*, the flash) in circuit *b*, and that for the other (*e. g.*, the click) by parallel wiring in both *a* and *c*. It was easy then, by a simple switch, to throw the latter apparatus from *a* to *c*. If it were in *a*, the order of stimuli was *a b* (*i. e.*, click leading, flash following); if in *c*, the order was *b c* (*i. e.*, flash leading, click following). The break-key of circuit *b* was fixed permanently in a middle position. In adjusting the apparatus the keys for *a* and *c* were set to make equal intervals on either side of *b*. Except in a few preliminary experiments, the subject and operator were in separate rooms.

When the operator was about to give the stimuli, he sent a ready-signal by a telegraphic key and sounder, and then broke the circuits for the stimuli by dropping the pendulum. As soon as the subject had received the stimuli, he returned his judgment of their order in the same way. After a series of twenty judgments there was usually an interval of rest, or the operator and subject changed places. One hundred judgments (five groups of twenty each) were taken in nearly every case before the conditions were varied. The Method of Right and Wrong Cases was used, the subject being given the stimuli an equal number of times in each order; with the click and flash, for example, click-flash fifty times was mixed irregularly with flash-click fifty times. In cases of doubt the subject was required to guess. Of those who served as subjects, *S* was practiced both in general psychological experimentation, and in this particular kind of work; *D* had had general practice, but *Si* and *H* had had neither.

I.

Experiments with Unforced Attention.

The first thing to be undertaken was a study of the matter under normal conditions of attention. The general results of experiments on this point can be most briefly reviewed in connection with the following tabulated record:

TABLE I.

Group I. *Stimuli addressed to disparate senses; attention at a balance.*[1]

STIMULI.	Interval.	Subject.	Date.	Number of Tests.	Percentage of correct replies.	
					Flash first.	Click first.
Flash and Click.	*18σ	H	A 6	100	70	40
	29	S	A 9	"	73	67
	"	"	"	"	74	72
	* "	H	"	"	66	42
	44	"	A 10	"	75	52
	"	"	"	"	84	62
					Flash first.	Shock first.
Flash and Shock.	44σ	S	A 11	100	73	86
	"	H	A 11-12	"	62	62
					Click first.	Shock first.
Click and Shock.	*18σ	S	A 7-8	100	40	74
	* "	H	A 1-2	120	48	78
	30	Si	J 22-25	70	72	81
	31	H	J 21	100	67	87
					Snap first.	Shock first.
Snap and Shock.	44σ	S	A 11	100	62	96
	"	H	"	"	62	62

[1]The experiments of Dr. Tracy, above referred to, were all of this type. The conditions were practically the same as those above described, except that the room in which the subject sat was partially darkened. His subjects were somewhat experienced in

Group II. *Stimuli addressed to different organs of the same sense; attention at a balance.*

Stimuli.	Interval.	Subject.	Date.	Number of Tests.	Percentage of correct replies.	
					Right first.	Left first.
	18σ	S	A 1	100	[85]	[77]
Two	"	D	J 24-26	"	[90]	[81]
	"	H	J 24-25	143	[59]	[81]
Clicks.	"	"	J 26	105	[58]	[88]
	29	"	J 23-24	86	[84]	[81]
	18σ	S	A 2	100	66	74
Two	"	Si	A 4	"	58	64
	"	H	A 2	"	62	64
Shocks.	*29	S	A 8	40	90	75
	* "	H	"	"	85	80

The asterisks (*) indicate experiments omitted in making Table II below, A = August, J = July.

The experiments in which two clicks were used, bracketed figures in Group II, require a word of explanation. After experiments in this form were over, it was discovered that whenever the circuit of the right telephone was broken, a current was induced in the left circuit sufficient to cause a faint click

laboratory work, but had had little or no special training for this experiment.

Interval.	Subject.	Number of Tests.	Percentage of correct replies.	
			Flash first.	Click first.
13.7σ	S	200	58	55
	Da	100	52	38
	L	100	74	44
	B	100	54	50
	Do	100	66	56
	T	200	79	71
50σ	S	100	98	96
	Da	100	86	70
	L	100	66	68
	B	100	68	74
	Do	100	80	58
	T	100	94	92

in the left telephone. It might be supposed that this would tend to obscure the order of the clicks, especially when the right was given first, but this is believed not to have been the case. It is a well established fact that continuous sounds heard strongly by one ear and faintly by the other, are heard only on the side of the ear receiving the louder sound, and there seems to be no reason for thinking this untrue of clicks also. The fact that in the course of the experiments the presence of this faint induced click was never recognized is in accord with this hypothesis. A grain of evidence on the other side might appear to exist in the greater proportion of correct answers in the case of *H*, when the 18σ interval was used, but this is made doubtful by the non-appearance of the constant error with the 29σ interval. It seems a good deal more likely that with the shorter interval we have simply a case of well-marked constant difference. It is perhaps of interest to mention that both *S* and *H* hear more acutely with the left than the right ear, and *H* a good deal more acutely with either ear than *S*.

In order to facilitate comparison of the general results of this table, the intervals required to give 75% of right answers have been calculated according to the table in Cattell and Fullerton's work, "On the Perception of Small Differences" (p. 16), and are given in Table II. Since the object here is not

TABLE II.

Intervals required to give 75% of right judgments, compared with results of Exner, Tracy and Bloch.

	F-C	C-F	F-S	S-F	C-S	S-C	C - C		S - S	
							Left first.	Right first.	Left first.	Right first.
	32σ	37σ	48σ	28σ	(98σ)	(17σ)	16σ	12σ	19σ	30σ
Si	—	—	—	—	35	23	—	—	34	60
D	—	—	—	—	—	—	14	9	—	—
H	35	169	98	98	48	19	15	44	34	40
					(98)	(98)				
Exner.	160	63	71	53	—	—	64	64	—	—
Tracy.	44	67								
Bloch.	28	36								

F = flash ; C = click ; S = shock.
Figures in parenthesis under C-S and S-C were gotten with a snap of an electric spark instead of the click of a telephone.

the exact record of results, but a picture of the phenomena under examination, some series of tests (those starred in Table I) have been omitted, four because the size of the interval used did not give results suited for calculation, and two because the number of tests was small; all other series of Table I have been included. With the same end in view, the results from tests made with different intervals have been combined. It hardly need be said that no importance is attached to the precise figures thus calculated, and no statements are made with regard to them that are not justified by the original records. The records of Exner, though made under different conditions and by a different psychophysical method, together with those of Tracy and Bloch are added for comparison.

The most noticeable thing in this table is the frequency of large constant differences; *S*, for example, in the combinations of flash and shock, requires a considerably larger interval if the order is F-S than if it is S-F, and *H* requires a much greater interval for C-F than for F-C. Some of these are evidently personal differences, one observer succeeding best with one order, the other finding no difference or succeeding best with the other. Reference to Table I shows also that some of the differences seem to depend on the general difficulty of making any judgment, and disappear, or even take the opposite sign when the interval is increased. This, at least, is the case for *H* in the C-C experiments and for *S* in the S-S experiments.

A tolerable unanimity, however, was found with the flash-and-click combination; the interval required for C-F was always larger than for F-C. In several series the difference is so slight that it may be accidental, but in others it is marked and in all there is no contrary case. In Tracy's twelve series there are only two instances of differences in the contrary direction, and these are slight in amount. In the experiments of Bloch, if the two studies are comparable, the same is to be observed. This is the more interesting as it is flatly opposed to the direction of the constant difference as observed by Exner in all seven of his subjects.[1] The relation is too constant in both cases to be set down as mere accident, and must be referred to some variation in the conditions of experimentation. The variations are so numerous that it is hard to fix with certainty upon the particular one, but three

[1] Gonnessiat also concludes from his experiments that the visual stimulus (the instantaneous flash of an artificial star) must precede the auditory (telephone click) by about 50σ, in order that they seem simultaneous, thus supporting Exner.

have a certain plausibility. In the first place, Exner's records are all naïve; in order to equalize the effect of practice, all practice was excluded and short series were taken on unpracticed subjects. In the long series of Tracy and the writer, the subjects could not remain unpracticed, and it may be that with increasing expertness changes in the direction of the constant differences occur. The records of the writer's experiments, while not very conclusive on this question, do not give evidence of such a change. In most of Exner's experiments, also, attention seems to have been given chiefly to one stimulus or the other, while in the writer's it was held in balance. It seems more likely, however, that the contrary direction of the constant difference depends on the fact that series of pairs of stimuli were used in one case and single pairs in the other.[1] In his experiments on personal equation, Gonnessiat finds rhythm a very important factor, and it may have been effective in these experiments of Exner's. Why Gonnessiat himself should have gotten such results as he did in trying to make the two stimuli seem simultaneous, is not easy to explain from data at hand, but it is highly probable that getting a coincidence of the two sensations is quite a different process from determining which comes first.

Whatever the cause may be, the fact remains that for single pairs of stimuli and for many observers the order F-C requires a less, or at most no greater interval than the order C-F, and this necessitates a revision of the explanation offered for the constant difference by Exner,[2] which makes the difference depend on the slower rise and greater duration of the visual sensation. The constant differences also that occur in the case of the click and shock, and especially those in case of stimuli to different organs of the same sense, cannot well be made to fit with an explanation based wholly on sensory inertia. It is more natural to refer the phenomenon, as Wundt does chiefly (Phys. Psy., 4te Aufl., II, 392), to differences in the direction of attention, either habitual or depending on the nature and intensity of the stimulus, the sensation receiving preponderant attention appearing to come first. Habitu alattention to what may be seen, in preference to what may be heard, is characteristic of many minds. The electric shock in the touch experiments, also, though not distinctly greater in intensity than the flash and click, would probably be regarded by most subjects as more intrusive.[3]

[1] *Op. cit.*, pp. 430-431.
[2] *Op. cit.*, p. 425.
[3] A delay in the response of the telephones, if such there were, might explain some of the cases, but such a delay is practically out

II.

Experiments with Forced Attention.

Experiments on Voluntarily Directed Attention. The experiments were undertaken in full expectation of finding a definite relation between the direction of attention and the apparent order of the stimuli. Several short series of experiments were made with different pairs of stimuli, (a total of 360 for *S*, and of 278 for *H*), but nothing like a definite connection could be made out, and the experiments were broken off. So far as the figures showed anything, they showed that forced attention was as often a hindrance as a help, even when the leading stimulus was attended to, and that attention to the following stimulus was often advantageous. A good deal of support is given to the conclusion that voluntary attention is ineffective by the general observation that the best results were reached when the subject was in a state of indifference. Of this, more will be said presently.

Experiments on Involuntarily Directed Attention. Experiments with stimuli of different intensities were made in the expectation that the fainter stimulus could be so far reduced as to compel the subject's attention involuntarily to it through his fear of losing it. This seems to have succeeded with *H*; for the faint sound was often lost altogether, and she felt a straining of the attention towards the weaker stimulus. Yet, when heard, it usually seemed to lead and gave the subject 80% right when the weak sound led, to 32% when the loud sound led. The record of *S* showed the opposite tendency. He seems not to have felt the compulsion toward the weaker stimulus, but allowed his attention to balance indifferently between the two until one sound was made very faint, and then felt only an occasional tendency to listen for the weaker sound. When the stronger stimulus led, this subject had 92% of his judgments right, when the weaker led, only 42%. Differences like these seem to indicate an individual caprice of the attention. It is caught in one

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of the question. With the apparatus at hand, it was not possible to measure the delay of the telephone plate when it moved as little as in these experiments. Chronographic tests, when a stronger current was used showed no appreciable delay. No regard was had in the experiments to whether the first movement of the telephone plate was toward the ear or away from it, but the differences in time introduced by this must be extremely small. This problematic influence of the apparatus was completely avoided, when the snap of an induction spark was substituted for the telephone click. With *H* this seemed to make a difference; with *S*, however, the constant error remained as before.

case by a loud sound, in the other by a faint sound. And the individual tendency is so persistent, that even when a subject knows that his attention has been partial to one stimulus, he cannot correct the tendency. All these attention experiments seem to show, in a single word, the helpfulness of spontaneous as opposed to voluntary attention.

Besides the experiments already mentioned, a few records were taken when three stimuli were given the subject. The click and the shock were sent at the same instant, and separated from the flash by an interval of 18σ. The subject recorded the apparent order of the three. Both subjects found that the click seemed to lag behind the other two stimuli, and noticed a growing tendency to ignore the sound altogether, making the experiment practically a repetition of the flash and shock tests, at a shorter interval.

A certain interest may attach to the following general observations:

When an observer is practiced the interval between the stimuli sometimes seems quite an extensive period of time. In judging the order of a flash and click at an interval of 18σ, *S* noticed several times that he distinctly waited for the second stimulus. When the flash came first he had a definite sensation of darkness before hearing the click. *H* noticed something similar at times. When listening to the two clicks at an interval of 30σ, this subject had a muscular sensation apparently intervening between the two sounds, as if the interval had been long enough for the attention to shift its muscular adjustment after receiving the first, before taking in the second.

The interpretation of the successive stimuli in terms of motion, noticed by Exner was frequently observed in these experiments. It was prominent in the two shock experiments and in those with the flash and shock, but with the two clicks it was much fainter or entirely absent.

III.

Conclusions.

During the progress of the experiments the chief subjects were on the watch for introspective suggestions, but introspection under the conditions of this experiment proved unusually hard, and not much was obtained in this way. A little light is furnished, however, by an observation, partly introspective, partly external, which was early made by Tracy and was repeatedly confirmed in the writer's experiments, namely, that the best results were reached when the subject assumed a certain indifference, awaited the stimuli

without strained attention and based his reply upon a "general feeling" of their order rather than on a clear recognition of it. The condition of mind may be most accurately designated as "alert indifference," a condition in which voluntary effort furnishes the general ground, but nothing more. The subject was always in an easy and unconstrained position, but the muscles of the head, of breathing, of the eye, ear, or hand, were somewhat innervated. This was occasionally shown by some slight muscular reaction; the hand would twitch in response to a very faint electric shock, or the eyes would wink when the flash came. But along with this degree of sensitiveness or alertness, there was a mental nonchalance. The subject was in a passive state, free from any sense of care or effort, and with no lasting memory of what was taking place. If a judgment was not recorded at once, it could not be given at all.[1]

The hypothesis which the experiments have suggested with reference to the psychophysical mechanism by which such judgments of order are made is briefly as follows: The sudden entrance of any stimulus causes an immediate reflex response of adjustment in the organ in case of the eye and ear, and perhaps of withdrawal of the member in the case of the hand. What is really compared in judging the order of the stimuli, is not the special sense impressions, but the sensations resulting from these reflex movements. In order that these reflex responses may be prompt, the subject must be alert, but must not be voluntarily attentive, because voluntarily attention causes beforehand a more or less complete adaptation of the organs in question, and thus obscures the reflex response. The problem would then become one of the necessary length of the just observable interval between two sensations of movement, a problem on which, so far as the writer knows, no other data are extant.

This conception of the mechanism and the observations on which it rests, agree well with the first of Exner's several types of attention. The first is thus described: (p. 429) "We adjust our attention for the first stimulus that is to reach us, of course without knowing which it is; and not for this alone, but also — I cannot express myself differently — for the condition of the sensorium at the instant of this first stimulus. By this adjustment that instant is fixed in memory, and which of the two stimuli was the one adjusted

[1] To *S* it sometimes seemed that there was a certain tendency to regard the sensation which seemed stronger in consciousness as the first, if the judgment was made from recollection and not from immediate sensation, but he is unwilling to attach much importance to this observation.

for can be recognized in the memory image; that one is then the first. The second stimulus is wanting in this memory image in so far as the image results from an exact adjustment. The limit of the discriminable is reached, when it is no longer possible to fixate the first stimulus alone." This method was noticed by Exner only in the case of the separate stimuli to the two ears, and, while he thinks it may possibly have occurred in the other cases also, he is inclined to believe that the close resemblance of the two-stimuli is an essential condition of its development. This restriction seems doubtful; at least, in the experiments of this study, no difference in type was noticed in the different combinations of stimuli. It is much more probable that this type is characteristic of experiments in which a single pair of stimuli are judged, and that the type which Exner found for stimuli to disparate senses belongs to the rhythmically recurring pairs of stimuli. As already explained, the two click experiments of Exner were the only ones where his apparatus seems to have allowed the production of a single pair.

The results of this study may be summarized briefly as follows:

1. The interval that must separate instantaneous stimuli addressed to disparate senses, or to different organs of the same sense in order that their order may be recognized, has been measured for single pairs of stimuli, and by a method as nearly as possible the same in all cases. The results of this measurement, besides indicating some changes in the figures commonly given for these intervals, make the explanation of the constant errors, found with the click and flash, by optical inertia apparently unnecessary.

2. The effect of voluntary attention has been examined, and so far as the experiments go, has been shown not to cause the stimulus for which attention is set to seem to lead in time. Throughout the experiments, on the contrary, the importance of spontaneous attention, or at least the spontaneous reaction of the psychophysical mechanism has everywhere appeared.

XI. Notes on New Apparatus.

By Edmund C. Sanford.

The Binocular Stroboscope. The purpose of this note is the double one of calling attention to a little known phenomenon of binocular vision and describing an instrument by which it